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SYSTEM AND METHOD FOR CLASSIFYING IN VIVO IMAGES
ACCORDING TO ANATOMICAL STRUCTURE

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SYSTEM AND METHOD FOR CLASSIFYING IN VIVO IMAGES
ACCORDING TO ANATOMICAL STRUCTURE

FIELD OF THE INVENTION

5 The present invention relates generally to an in vivo camera system and, in particular, to classifying images captured by an in vivo camera system according to anatomical structure.

BACKGROUND OF THE INVENTION

10 Several in vivo measurement systems are known in the art. They include swallowable electronic capsules which collect data and which transmit the data to a receiver system. These intestinal capsules, which are moved through the digestive system by the action of peristalsis, are used to measure pH ("Heidelberg" capsules), temperature ("CoreTemp" capsules) and pressure throughout the
15 gastrointestinal (GI) tract. They have also been used to measure gastric residence time, which is the time it takes for food to pass through the stomach and intestines. These intestinal capsules typically include a measuring system and a transmission system, where a transmitter transmits the measured data at radio frequencies to a receiver system.

20 U.S. Patent No. 5,604,531, assigned to the State of Israel, Ministry of Defense, Armament Development Authority, and incorporated herein by reference, teaches an in vivo measurement system, in particular an in vivo camera system, which is carried by a swallowable capsule. In addition to the camera system there is an optical system for imaging an area of the GI tract onto the
25 imager and a transmitter for transmitting the video output of the camera system. The overall system, including a capsule that can pass through the entire digestive tract, operates as an autonomous video endoscope. It images even the difficult to reach areas of the small intestine.

 FIG. 1 shows a block diagram of the in vivo video camera system
30 described in U.S. Patent No. 5,604,531. The system captures and transmits images of the GI tract while passing through the gastrointestinal lumen. The

system contains a storage unit **100**, a data processor **102**, a camera **104**, an image transmitter **106**, an image receiver **108**, which usually includes an antenna array, and an image monitor **110**. Storage unit **100**, data processor **102**, image monitor **110**, and image receiver **108** are located outside the patient's body. Camera **104**,
5 as it transits the GI tract, is in communication with image transmitter **106** located in capsule **112** and image receiver **108** located outside the body. Data processor **102** transfers frame data to and from storage unit **100** while the former analyzes the data. Processor **102** also transmits the analyzed data to image monitor **110** where a physician views it. The data can be viewed in real time or at some later
10 date.

During a typical examination, the in vivo camera system may take anywhere from about four to eight hours or more to traverse the digestive tract. Assuming a capture rate of about 2 images per second, the total number of captured images can range from approximately 35,000 to 70,000 or more. If these
15 images were subsequently displayed as a video sequence at a rate of 30 frames per second, one would require 20-40 minutes of viewing time to observe the entire video. This estimate does not include the extra time needed to zoom in and/or decrease the frame rate for a more detailed examination of suspect areas.

In some situations, the physician may desire to view only a portion
20 of the video related to a certain anatomical structure. For example, if Crohn's disease is suspected based on symptoms such as abdominal pain, weight loss, iron deficiency anemia, diarrhea, an elevated erythrocyte sedimentation rate, or fever, then the in vivo camera system might be used to locate ulcerations within the small intestine. In this case, the physician may be interested in viewing only the
25 segment of the video pertaining to the small intestine, and may not have the time or inclination to cue the video manually to find the beginning of the small intestine.

One remedy to this situation is to limit the capture frequency of the in vivo camera system until the capsule reaches the small intestine. For example,
30 PCT Application WO 01/65995, assigned to Given Imaging Ltd., discloses a system for shutting down the imager and other device electronics for a period of

approximately two hours until the capsule reaches the small intestine. This period of approximately two hours is derived solely from the known average motility of the human digestive tract. It does not rely on any patient specific information.

Patient specific motility information can be used to adjust the capture frequency of the in vivo camera system, as is described in PCT Application WO 01/87377, also assigned to Given Imaging Ltd. However, neither average motility information nor patient specific motility information is enough to accurately pinpoint the anatomical structure or structures being captured in particular in vivo images or video segments.

PROBLEM TO BE SOLVED BY THE INVENTION

The present invention solves the problem of presenting the physician with pertinent in vivo images or video segments of a specific anatomical structure, without requiring the physician to cue an entire in vivo video manually in order to find the desired anatomical structure. Furthermore, the present invention solves the problem of adjusting the capture frequency of the in vivo camera system in accordance with the anatomical structure or structures being captured.

SUMMARY OF THE INVENTION

The aforementioned need is met according to the present invention by providing a system for identifying anatomical structure depicted in an in vivo image. The present invention includes an examination bundlette having a captured in vivo image; and a gastrointestinal atlas that includes a list of individual anatomical structures and characterization data of the individual anatomical structures. A classification engine analyzes the examination bundlette and the gastrointestinal atlas to identify the anatomical structure depicted in the captured in vivo image.

ADVANTAGEOUS EFFECT OF THE INVENTION

The present invention has the following advantages: First, automatic classification of in vivo images according to anatomical structure enables the physician to view in vivo images of a specific anatomical structure or structures without having to waste valuable time in manually searching the in vivo video. Second, adjusting the capture rate enables any desired anatomical structure to be imaged more frequently than non-desired anatomical structures. This provides a mechanism for yielding a more detailed analysis of the desired anatomical structure to the physician, while simultaneously optimizing the power consumption of the in vivo capsule.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages of the present invention will become more apparent when taken in conjunction with the following description and drawings wherein identical reference numerals have been used, where possible, to designate identical features that are common to the figures, and wherein:

FIG. 1 (PRIOR ART) is a block diagram illustration of an in vivo camera system.

FIG. 2A is an illustration of an examination bundle.

FIG. 2B is an illustration of an examination bundlette.

FIG. 3 is a block diagram illustration of the system of the current invention for identifying anatomical structure depicted in an in vivo image.

FIG. 4 is an illustration of a GI atlas.

FIG. 5 is a block diagram illustration of the method of the current invention for adjusting the capture frequency of an in vivo camera system.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION OF THE INVENTION

In the following description, various aspects of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well-known features may be omitted or simplified in order not to obscure the present invention.

During a typical examination of a body lumen, the in vivo camera system captures a large number of images. The images can be analyzed individually, or sequentially, as frames of a video sequence. An isolated image or frame without context has limited value. Some contextual information is frequently available prior to or during the image collection process; other contextual information can be gathered or generated as the images are processed after data collection. Any contextual information will be referred to as metadata. Metadata is any information that is not pixel data, such as the image header data that accompanies many digital image files.

Referring to Figure 2A, the complete set of all images captured during the examination, along with any corresponding metadata, will be referred to as an examination bundle **200**. The examination bundle **200** consists of a collection of image packets **202** and a section containing general metadata **204**.

An image packet **206** comprises two sections: the pixel data **208** of an image that has been captured by the in vivo camera system, and image specific metadata **210**. The image specific metadata **210** can be further refined into image specific collection data **212**, image specific physical data **214** and image specific inferred data **216**. Image specific collection data **212** contains information such as the frame index number, frame capture rate, frame capture time, and frame exposure level. Image specific physical data **214** contains information such as the relative position of the capsule when the image was captured, the distance traveled from the position of initial image capture, the instantaneous velocity of the

capsule, capsule orientation, and non-image sensed characteristics such as pH, pressure, temperature, and impedance. Image specific inferred data **216** includes location and description of detected abnormalities within the image, and any pathologies that have been identified. This data can be obtained either from a physician or by automated methods.

The general metadata **204** contains such information as the date of the examination, the patient identification, the name or identification of the referring physician, the purpose of the examination, suspected abnormalities and/or diagnosis, and any information pertinent to the examination bundle **200**. It can also include general image information such as image storage format (e.g., TIFF or JPEG), number of lines, and number of pixels per line. It will be understood and appreciated that the order and specific contents of the general metadata or image specific metadata may vary without changing the functionality of the examination bundle.

In some scenarios, general metadata **204** may be required before the examination bundle **200** has been fully constructed. For example, a physician may wish to monitor captured images in real time as the capsule passes through the GI tract in order to closely search a region for a suspected abnormality. In these scenarios, we will encapsulate the general metadata **204** with a specific image packet **206** to form an examination bundlette **220**, as illustrated in Figure 2B.

The present invention describes a method and system for identifying the anatomical structures pertaining to specific images or video segments captured by the in vivo camera system. Figure 3 illustrates a system for identifying the anatomical structure pertaining to a specific image. The system takes as input an examination bundlette **300** and a GI atlas **302**, and passes them into a classification engine **304**. The classification engine **304** identifies the anatomical structure pertaining to the image packet of the examination bundlette **300**, and yields as output the identified anatomical structure **306**.

Figure 4 illustrates the GI atlas **302** that is provided to the classification engine **304** of Figure 3. The GI atlas **302** is defined to be a list of anatomical structures, along with any pertinent characterization data for each

individual anatomical structure. In the preferred embodiment, the list of anatomical structures includes the mouth, pharynx, esophagus, cardiac orifice, stomach, pylorus, duodenum, jejunum, ileum, ileocecal valve, cecum, colon, rectum, and anus. This list is not restrictive, however; other embodiments may include a subset of these anatomical structures, a more detailed set of anatomical structures, or a combination of structures (e.g., small intestine instead of duodenum, jejunum, and ileum). For a specific anatomical structure **400**, pertinent characterization data may include a structure label **402**, non-image specific characterization data **404**, and image specific characterization data **406**.

The structure label can simply be the anatomical name of the structure, such as mouth, pharynx, etc., or an index or key denoting the structure. Characterization data can include any type of data that describes or characterizes the anatomical structure. Non-image specific characterization data **404** can include the average length or size of the structure, average relative position of the structure along the GI tract and/or with respect to other anatomical structures, average pH, temperature, and pressure levels of the structure, average motility characteristics of the structure, etc. Image specific characterization data **406** can include representative images of the anatomical structure captured from various positions and orientations, and from various illumination levels, color and/or texture distributions or features of representative images of the structure, etc.

Characterization data is not limited to the specific types of data described herein; rather, any data deemed pertinent to the identification of anatomical structure can be included in the non-image specific or image specific characterization data.

The classification engine **304** takes as input an examination bundle **300** and the GI atlas **302**, and executes a method for identifying the particular structure in the GI atlas **302** that is imaged in the examination bundle **300**. A variety of classification methods, among them image and non-image based classification methods, can be executed by the classification engine **304**. For an in-depth discussion of classification methods, see R. O. Duda and P. E. Hart, *Pattern Recognition and Scene Analysis*, New York: John Wiley, 1973. In the preferred embodiment, a supervised learning scheme is used to perform the

classification. One or more feature vectors are derived from the non-image specific characterization data **404** and/or image specific characterization data **406** for each structure, generating prototypes describing each anatomical structure. These prototypes can be generated prior to classification of a particular examination bundle; in the preferred embodiment, they are generated prior to the examination and stored in the characterization data of the GI atlas **302**.

A feature vector is then derived from the general metadata **204**, the pixel data **208**, and/or the image specific metadata **210** of the examination bundle **300**. The derived feature vector is then classified to the class described by the prototypes of a particular anatomic structure. This classification can be performed in many different ways. If the class whose centroid is closest to the derived feature vector is chosen, the classifier is the well-known minimum mean Euclidean distance classifier. If the class containing the maximum number of neighbors out of the k nearest neighbors to the derived feature vector is chosen, the classifier is the well-known k -nearest neighbor classifier. Other types of classifiers can be used as well, such as linear, piecewise linear, quadratic, or polynomial discriminant functions, decision trees, neural networks, support vector machines, or the like. In this way, the classification of the derived feature vector by the classification engine **304** identifies the anatomical structure **306** associated with the examination image bundle **300**.

A number of embodiments of the present invention are possible depending on the choice of characterization data used to generate the prototypes and the feature vector of the examination bundle. For example, in one embodiment, the prototypes are constructed solely with features from the image specific characterization data **406** for each structure in the GI atlas **302**. Such features could include color information, texture information, morphological information, or any information extracted from representative images of each anatomical structure. Whatever features are used to construct the prototypes should also be the features extracted from the examination bundle prior to classification. In another embodiment, the prototypes are constructed solely with features from the non-image specific characterization data **404** for each structure

in the GI atlas **302**. For example, prototypes can be constructed with features that describe the length, absolute position, and/or relative position of the anatomical structures within the GI tract. The classification engine **304** can extract the position information of the capsule from the examination bundle **300**, integrate
5 the position information to determine the absolute distance traveled, and identify the anatomical structure by choosing the one whose absolute position is the same as the absolute distance traveled. In another embodiment, the prototypes are constructed with both the non-image specific characterization data **404** and the image specific characterization data **406**. For example, prototypes can be
10 constructed with features derived both from the image data itself, and from the position data of the capsule.

Figure 5 is a block diagram illustration of a method for adjusting the capture rate of an in vivo camera system in accordance with anatomical structure. A GI atlas **500**, as described in Figure 4, is provided. Next, a selection
15 set **502** is constructed containing at least one anatomical structure **400** from the GI atlas **500**. Next, a capture rate is associated **504** with each anatomical structure in the selection set **502**. If the selection set **502** contains more than one anatomical structure, then the capture rates for two or more of the anatomical structures in the selection set may be identical, or the capture rates for each anatomical structure in
20 the selection set may be unique. In the preferred embodiment, the selection set contains one or more anatomical structures of interest to the physician. For example, if Crohn's disease is suspected, the physician may only be interested in images of the small intestine. In this example, the selection set **502** may be chosen to contain only the duodenum, jejunum, ileum, and the capture rates **504**
25 associated with these structures are chosen to be larger than the default capture rate of the in vivo system.

Now, in step **506**, in vivo images are captured at a first capture rate. Every time an in vivo image is captured, an image packet **508** is produced, as described in the description of Figure 2A. For at least one image packet **508**, an
30 examination bundle **510** is formed, as described in the description of Figure 2B. The examination bundle **510** and GI atlas **500** are input into the system of

Figure 3, which, in step **512**, identifies the anatomical structure imaged in the examination bundle. Upon identification of the anatomical structure **512**, a query **514** is made as to whether the identified anatomical structure **512** is an element of the selection set **502**. An affirmative response to query **512** indicates that the first capture rate of the in vivo camera system is adjusted **516** to the capture rate **504** associated with the identified anatomical structure **512**. A negative response to query **512** indicates that the first capture rate remains unchanged.

The method illustrated in Figure 5 can be extended to account for different capture rates associated with more than one anatomical structure. For instance, after the capture rate adjustment step **516**, the first capture rate can be redefined as the adjusted capture rate, and steps **506** through **516** can be repeated. This entire process can be continued for the duration of an in vivo examination. In addition, this process can encapsulate situations where the physician wants the in vivo camera system to return to a default capture rate when the identified anatomical structure is not contained in the selection set. This is accomplished by taking all of the anatomical structures that are listed in the GI atlas **500** but not in the selection set **502**, including them in the selection set **502**, and associating with them the default capture rate in step **504**.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100	Storage Unit
102	Data Processor
104	Camera
106	Image Transmitter
108	Image Receiver
110	Image Monitor
112	Capsule
200	Examination Bundle
202	Image Packets
204	General Metadata
206	Image Packet
208	Pixel Data
210	Image Specific Metadata
212	Image Specific Collection Data
214	Image Specific Physical Data
216	Image Specific Inferred Data
220	Examination Bundlette
300	Examination Bundlette
302	GI Atlas
304	Classification Engine
306	Identified Structure
400	Anatomical Structure
402	Structure Label
404	Non-Image Specific Characterization Data
406	Image Specific Characterization Data
500	GI Atlas
502	Selection Set
504	Associate Capture Rate Step
506	Capture In Vivo Images Step
508	Image Packet

- 510 Examination Bundlette
- 512 Identify Structure Step
- 514 Query
- 516 Adjust Capture Rate Step